CP Violation: Recent Results from BABAR

Gautier Hamel de Monchenault

CP VIOLATION: RECENT RESULTS FROM *BABAR*

G. Hamel de Monchenault[a],
on behalf of the *BABAR* Collaboration
DSM/Dapnia, CEA/Saclay,
F-91191 Gif-sur-Yvette, France

We review recent time-dependent measurements in the B meson sector based on data collected between 1999 and 2002 by the *BABAR* detector, which correspond to approximately 88 millions $B\overline{B}$ pairs.

1 Introduction

The striking agreement with the Standard Model predicted value [3] of direct measurements of $\sin 2\beta$ at B Factories, by *BABAR* [1]

$$\sin 2\beta \quad = \quad 0.741 \pm 0.067\,(\mathrm{stat}) \pm 0.034\,(\mathrm{syst}) \tag{1}$$

and Belle [2] experiments, leaves little room for sizable New Physics contribution to the $B^0\overline{B}^0$ flavor mixing [4]. Because $\sin 2\beta$ is turning to a precision measurement, *BABAR* has started to test experimentally some of the basic assumptions in the interpretation of the time-dependent CP asymmetry in "Golden" charmonium modes in terms of $\sin 2\beta$ [5]: constraints on direct CP violation in $B \to J/\psi\, K$ decays; limit on wrong-flavor transitions in $B \to J/\psi\, K$ decays; test of CPT conservation and limits on CP and T non-conservation in $B^0\overline{B}^0$ mixing; and limit on the lifetime difference between neutral B mesons. In addition are performed measurements of $\sin 2\beta$ using various neutral B decay modes involving different short-distance physics: ϕK^0_S, $\eta' K^0_S$, $D^{\star\pm}D^{\mp}$, $D^{\star+}D^{\star-}$ and $J/\psi\,\pi^0$; and time-dependent CP asymmetry measurements in charmless B decay modes, $\pi^+\pi^-$ and $\rho^\pm\pi^\mp$, which are related to angle α of the Unitarity Triangle.

[a] e-mail address: gautier@hep.saclay.cea.fr

1.1 The data set

Unless specified otherwise, the measurements presented in this paper are based on a data sample of about 88 million $B\overline{B}$ pairs collected between 1999 and 2002 with the *BABAR* detector at the PEP-II asymmetric-energy B Factory at SLAC. This corresponds to an integrated luminosity of approximately $92\,\mathrm{fb}^{-1}$ at the $\Upsilon(4S)$ resonance. We also exploit a sample of $9\,\mathrm{fb}^{-1}$ of data taken 40 MeV below the resonance (off-resonance data) for continuum background studies.

1.2 The BABAR detector

The *BABAR* detector is described in detail elsewhere [6]. The tracking system is composed of a cylindrical drift chamber (DCH) and a silicon vertex tracker (SVT), both operating in a 1.5-T solenoidal magnetic field. Charged particle identification is performed using a ring-imaging Cherenkov detector (DIRC) and $\mathrm{d}E/\mathrm{d}x$ information from tracking detectors. Electrons and photons are identified and their energy measured with a CsI electromagnetic calorimeter (EMC). Muons and neutral hadrons are identified in the instrumented flux return (IFR).

1.3 The $B^0\overline{B}^0$ system

There are three relevant bases to describe the neutral B meson system. The first basis is that of the two flavor eigenstates B^0 and $\overline{B}^0$, which are related through *CP* transformation. The second basis is that of the *CP* eigenstates of the system, B_+ and B_-. The third basis is that of the physical states that propagate with definite mass and lifetime. The mass difference and width difference between the "heavy" B_H and "light" B_L mesons are defined as

$$\Delta m \equiv m_{B_H} - m_{B_L} > 0\,, \quad \Delta\Gamma \equiv \Gamma_{B_H} - \Gamma_{B_L}\ .$$

Δm, which is 2π times the $B^0\overline{B}^0$ flavor oscillation frequency, is measured with great accuracy. The present world average, $\Delta m = 0.502 \pm 0.006\ \mathrm{ps}^{-1}$, is dominated by measurements at B Factories [7]. A peculiarity of the $B^0\overline{B}^0$ system is that the oscillation frequency and the width are of the same order, $x_d = \Delta m/\Gamma = 0.755 \pm 0.015$. Only very loose constraints of the width difference, $\Delta\Gamma$, are available up to now[8]. In the Standard Model, $\Delta\Gamma/\Gamma$ is proportional to m_b^2/m_t^2 and thus is expected to be very small. A recent leading order calculation yields $\Delta\Gamma/\Gamma = -0.3\%$[9], but next-to-leading order corrections are expected to be large and may lead to an even smaller absolute value [10].

1.4 CP, T and CPT conservation in $B^0\overline{B}^0$ mixing alone

The discrete symmetries *CP* and T are expected to be violated in $B^0\overline{B}^0$ mixing alone, but at a very low level. *CP* and T violation can be characterized by the parameter q/p, where q and p are (assuming *CPT* invariance) the reduced complex coefficients that link the mass and flavor eigenstates of the system according to

$$|B_L\rangle = p\,|B^0\rangle + q\,|\overline{B}^0\rangle, \quad |B_H\rangle = p\,|B^0\rangle - q\,|\overline{B}^0\rangle\,.$$

The argument of q/p depends on phase conventions; therefore q/p is not an observable, but its modulus $|q/p|$ is. A departure of $|q/p|$ from 1 is a manifestation of both *CP* and T violation in $B^0\overline{B}^0$ mixing alone. In the Standard Model this effect is tiny: $|q/p| - 1 \simeq 4\pi\,\mathrm{m_c^2/m_t^2}\ \sin\beta \approx 5\times 10^{-4}$. For most applications one can write $q/p = e^{2i\phi_M}$, where $\phi_M = -\beta$ in the usual Wolfenstein phase convention [11].

CPT conservation, based on very general principles of relativistic quantum mechanics, relies on the locality of quantum field theories. However some theories in modern physics, such as string theories, are not local at very short distances. Therefore the *CPT* symmetry could be violated. We introduce the phase convention-independent complex parameter $z \equiv (\delta M - (i/2)\delta\Gamma)/(\Delta m - (i/2)\Delta\Gamma)$, where δM and $\delta\Gamma$ are differences between the diagonal elements of the mass (dispersive) and lifetime (absorptive) components of the effective Hamiltonian describing the evolution of the neutral B meson system. $z \neq 0$ is a manifestation of both *CP* and *CPT* violation in $B^0\overline{B}^0$ mixing alone.

1.5 Time evolution at the $\Upsilon(4S)$

B Factories are energy-asymmetric e^+e^- colliders operating at an energy of $\sqrt{s} = 10.58\,\mathrm{GeV}$ on the $\Upsilon(4S)$ resonance. The $\Upsilon(4S)$ is the 4^3S_1 state ($J^{PC} = 1^{--}$) of the bottonium ($b\bar{b}$) system; it decays exclusively into a $B\overline{B}$ pair, B^+B^- or $B^0\overline{B}^0$ in nearly equal amounts. The $B^0\overline{B}^0$ system from a $\Upsilon(4S)$ decay evolves coherently: the two mesons flavor-oscillate in phase in such a way that at any moment in time, the system is the superposition of exactly one B^0 and one $\overline{B}^0$ meson. The decay of one meson serves as an analyzer of the state of the accompanying meson at that instant.

Experimentally, we reconstruct fully the decay on one of the two B mesons, that we label B_{rec}, into a final state f_{rec}. The other particles, which form the *rest of the event* (ROE), come from the decay of the second B meson, B_{tag}, into the final state f_{tag}. The odds of reconstructing fully the final state f_{tag} are small. Instead, we apply a flavor tagging algorithm to the ROE based on the presence of charged lepton, kaons, soft pions, and other kinematical properties. This algorithm determines the flavor of the B_{tag} with an effective efficiency (*i. e.* taking into account the probability of wrong flavor assignment) of $28.1 \pm 0.7\%$. The sample of selected events is divided according to the result of the flavor tagging algorithm, either B^0 or $\overline{B}^0$ tag. The proper time difference Δt between the two decays is deduced from the measurement of the distance Δz between the B_{rec} and B_{tag} decay vertices along the boost axis, which is measured with a resolution (RMS) of about $150\,\mu\mathrm{m}$. (At PEP-II, the distance between the two B vertices is $260\,\mu\mathrm{m}$ in average.)

We consider cases where f_{rec} is a *CP* eigenstate f_{CP}, *i.e.* such that $CP|f_{CP}\rangle = \eta_{f_{CP}}|f_{CP}\rangle$ with $\eta_{f_{CP}} = \pm 1$. We introduce a convention-independent complex parameter

$$\lambda_{f_{CP}} \equiv \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}},$$

where we use the notation $\overset{(-)}{A}_f \equiv \mathcal{A}(\overset{(-)}{B} \to f)$ for the complex decay amplitudes. The imaginary part of $\lambda_{f_{CP}}$ characterizes *CP* violation in the interference between $B^0\overline{B}^0$ mixing and B^0 or $\overline{B}^0$ decay while a value of $|\lambda_{f_{CP}}|$ different from 1 is an indication of direct *CP* violation in the decay (assuming that the effects of *CP* violation in $B^0\overline{B}^0$ mixing alone are negligible). The time-dependent *CP* asymmetry

$$a_{f_{CP}}(\Delta t) \equiv \frac{\mathcal{N}(\Delta t; B^0\,\mathrm{tag}) - \mathcal{N}(\Delta t; \overline{B}^0\,\mathrm{tag})}{\mathcal{N}(\Delta t; B^0\,\mathrm{tag}) + \mathcal{N}(\Delta t; \overline{B}^0\,\mathrm{tag})}$$

can be expressed (omitting effects of imperfect flavor tagging and time difference reconstruction) as

$$\begin{aligned} a_{f_{CP}}(\Delta t) &= -C_{f_{CP}}\,\cos(\Delta m\,\Delta t) + S_{f_{CP}}\,\sin(\Delta m\,\Delta t) \\ \text{with}\ \ C_{f_{CP}} &\equiv \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}\ \ \text{and}\ \ S_{f_{CP}} \equiv \frac{2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}\ . \end{aligned}$$

We also consider cases where f_{rec} is a flavor eigenstate, or very nearly so, *i.e.* such that $|\overline{A}_f| \ll |A_f|$. This larger sample is used to determine from the data the probabilities of wrong flavor-tag assignment and the parameters of the time resolution function.

2 Limit on direct CP violation in $J/\psi K$ decays

In the Standard Model CP violation is expected to be small in $B \to J/\psi K$ decays. The reason is that the sub-dominant contribution to the decay, a gluonic penguin amplitude, has the same weak phase as the dominant color-suppressed tree amplitude. The first contribution to the decay with a different phase is highly suppressed. One expects $|\overline{A}_{J/\psi K^0_S}/A_{J/\psi K^0_S}| - 1 \leq 10^{-2}$.

The test of the absence of direct CP violation in these decays is two-fold. On the $CP = -1$ sample used for the measurement of $\sin 2\beta$ we obtain [1]:

$$|\lambda_{J/\psi K^0_S}| = 0.948 \pm 0.051 \pm 0.030 \ . \tag{2}$$

We also measure the charge asymmetry for the isospin-related charged mode. Based on a sample of about 1300 $J/\psi K^{\pm}$ candidates selected in $20.7\,\mathrm{fb}^{-1}$ of data, we find [12]:

$$\mathcal{A}_{J/\psi K^{\pm}} = (\,0.3\ \pm 3.0\ \pm 0.4\,)\% \ . \tag{3}$$

Both results are consistent with no direct CP violation in $B \to J/\psi K$ decays.

3 Could $\sin 2\beta_{J/\psi K^0_S}$ and $\sin 2\beta_{J/\psi K^0_L}$ differ?

The main final states for the measurement of $\sin 2\beta$ are $J/\psi K^0_S$ and $J/\psi K^0_L$. Since the two measurements are combined, one may ask the question: How good is the relation

$$\sin 2\beta_{J/\psi K^0_S} = \sin 2\beta_{J/\psi K^0_L} \quad ? \tag{4}$$

The interference between $B^0 \to J/\psi K^0$ and $B^0 \to \overline{B}^0 \to J/\psi \overline{K}^0$ is possible thanks to $K^0\overline{K}^0$ mixing. Obviously relation (4) cannot be rigourously exact since the K^0_S and K^0_L physical states are not exactly CP eigenstates of the neutral kaon system. However the effect of indirect CP violation in $K^0\overline{K}^0$ mixing has negligible impact on (4). It has been shown [13] that the only effect that could spoil this relation would be a sizable wrong-flavor $B \to J/\psi \overline{K}$ transition, which is not possible at lowest orders in the Standard Model. To investigate the possibility of wrong-flavor decays, we study time-dependent rates on samples of 860 (resp. 856) self-tagged $J/\psi K^{*0}$ (resp. $J/\psi \overline{K}^{*0}$) candidates (selected with a purity greater than 96%). We obtain the preliminary measurements

$$\begin{aligned} \Gamma(\overline{B}^0 \to J/\psi K^{*0})/\Gamma(B^0 \to J/\psi K^{*0}) &= -0.022 \pm 0.028 \pm 0.016 \ , \\ \Gamma(B^0 \to J/\psi \overline{K}^{*0})/\Gamma(\overline{B}^0 \to J/\psi \overline{K}^{*0}) &= +0.017 \pm 0.026 \pm 0.016 \ , \end{aligned} \tag{5}$$

which are consistent with the absence of wrong-flavor $\bar{b} \to c\bar{c}s$ transitions, as expected.

4 Search for CP and T violation and test of CPT symmetry in $B^0\overline{B}^0$ mixing; limit on the lifetime difference.

The differential rates of $\Upsilon(4S) \to B\overline{B} \to f_{\rm rec} f_{\rm tag}$ events as a function of Δt has an exponential dependance $e^{-\Gamma|\Delta t|}$ modulated by a cosine and a sine term at the mixing frequency Δm. The exponential envelop is slightly modified by terms that depend on the lifetime difference $\Delta\Gamma$, while the coefficients of the cosine and sine terms receive small corrections that depend on the CP- and CPT-violating parameter z. From a simultaneous time-dependent fit to the CP and flavor eigenstate samples including tagged and untagged events, we obtain the following preliminary measurements [14]:

$$\begin{array}{rcllll} \mathrm{sign}(\mathrm{Re}\,\lambda_{CP}) \times \Delta\Gamma/\Gamma &=& -0.008 & \pm\ 0.037 & \pm\ 0.018 & [\,-0.084, +0.068\,] \\ |\,q/p\,| &=& 1.029 & \pm\ 0.013 & \pm\ 0.011 & [\,+1.001, +1.057\,] \\ (\,\mathrm{Re}\,\lambda_{CP}/\,|\,\lambda_{CP}\,|\,) \times \mathrm{Re}\,z &=& 0.014 & \pm\ 0.035 & \pm\ 0.034 & [\,-0.072, +0.101\,] \\ \mathrm{Im}\,z &=& 0.038 & \pm\ 0.029 & \pm\ 0.025 & [\,-0.028, +0.104\,] \end{array} \tag{6}$$

where the first errors are statistical, the second errors systematical, and 90% confidence level intervals are given under brackets. The first parameter, $\Delta\Gamma/\Gamma$ with a sign ambiguity, is consistent with zero within 4%. The second parameter, which measures *CP* and *T* violation in mixing, is consistent with unity within two standard deviations. The last two parameters, which are *CPT*-violating, are consistent with zero.

Systematics include possible biases due to charge asymmetries in the detector, which are estimated from the data, and a component that covers any effect due to quantum interference between the two decays when the $B_{\rm tag}$ undergoes a doubly-Cabibbo suppressed transition. Extensive systematic cross-checks include alternative measurements of $\sin 2\beta$ and Δm, which are fully consistent with *BABAR* published values and world averages. We also confirm that the ratio $|\overline{A}_{CP}/A_{CP}|$ is consistent with unity (no direct *CP* violation in $J/\psi K$) within 4.5%.

5 Measurements of $\sin 2\beta$ using non-$\bar{b}\to\bar{c}c\bar{s}$ modes

One of the most promising ways to look for New Physics at B factories is to measure the *CP* parameter $\sin 2\beta$ in several B decay modes sensitive to different short-distance physics.

The $B\to\phi K$ decay is dominated by a pure $\bar{b}\to\bar{s}s\bar{s}$ penguin transition. Our updated preliminary branching fraction and charge asymmetries measurements in these modes are

$$\begin{aligned} \mathcal{B}(B^0\to\phi K^0) &= (\,7.6\,^{+1.3}_{-1.2}\,\pm 0.5\,)\times 10^{-6} \\ \mathcal{B}(B^+\to\phi K^+) &= (\,10.0\,^{+0.9}_{-0.8}\,\pm 0.5\,)\times 10^{-6} \\ \mathcal{A}_{CP}(B^\pm\to\phi K^\pm) &= (\,3.9\,\pm 8.6\,\pm 1.1\,)\% \end{aligned} \tag{7}$$

and we place a limit on the $B^+\to\phi\pi^+$ decay

$$\mathcal{B}(B^+\to\phi\pi^+) < 0.38\times 10^{-6}\quad @\,90\%\,\mathrm{CL} \tag{8}$$

which indicates that the magnitude of rescattering in the ϕK final states is small [15]. The B decay final state ϕK^0_S is a *CP*-odd eigenstate. Any deviation from $S_{\phi K^0_S}=\sin 2\beta$ would be a strong indication of New Physics. We update our preliminary result [16] with a larger data set (84 million $B\overline{B}$ pairs) and augment it with the $K^0_S\to\pi^0\pi^0$ channel. Based on a sample of 51.5 ± 7.5 candidates in the $K^0_S\to\pi^+\pi^-$ channel and 13.3 ± 5.3 candidates in the $K^0_S\to\pi^0\pi^0$ channel we obtain:

$$S_{\phi K^0_S} = -0.18\pm 0.51\pm 0.07\ ,\quad C_{\phi K^0_S} = -0.80\pm 0.38\pm 0.12\ . \tag{9}$$

The large value of $C_{\phi K^0_S}$ reflects the mismatch between 27 B^0-tagged and 13 $\overline{B}^0$-tagged events in our signal sample. Fixing $C_{\phi K^0_S}$ to zero, we obtain $S_{\phi K^0_S}=-0.26\pm 0.51(\mathrm{stat})$.

The $B\to\eta' K$ decay is also a dominantly $\bar{b}\to\bar{s}s\bar{s}$ transition. However, because the η' meson has non-negligible $\bar{u}u$ component, the decay may also receive an additional $\bar{b}\to\bar{u}u\bar{s}$ contribution with a different weak phase. The predictions are that the size of this non-penguin contribution is relatively small. We measure the branching fractions and charge asymmetry [17]

$$\begin{aligned} \mathcal{B}(B^0\to\eta' K^0) &= (\,55.4\,\pm 5.2, \pm 4.0\,)\times 10^{-6} \\ \mathcal{B}(B^+\to\eta' K^+) &= (\,76.9\,\pm 3.5\,\pm 4.4\,)\times 10^{-6} \\ \mathcal{A}_{CP}(B^\pm\to\eta' K^\pm) &= (\,3.7\,\pm 4.5\,\pm 1.1\,)\% \end{aligned} \tag{10}$$

and time-dependent *CP* parameters

$$S_{\eta' K^0_S} = +0.02\pm 0.34\pm 0.03\ ,\quad C_{\eta' K^0_S} = +0.10\pm 0.22\pm 0.03\ . \tag{11}$$

Table 1: Summary of time-dependent measurements in various modes measuring $\sin 2\beta$, from the Heavy Flavor Averaging Group. The sign of the S coefficients for the $J/\psi\pi^0$ and $D^{*\mp}D^{\pm}$ modes are reversed to be directly comparable to the reference value of $\sin 2\beta$.

mode f	$-\eta_f \times S_f$ ("$\sin 2\beta$")	C_f	transition	references
Charmonium K_S^0	$+0.734 \pm 0.055$	$+0.052 \pm 0.047$	$\bar{b} \to \bar{c}c\bar{s}$	*BABAR* [1], Belle [2]
ϕK_S^0	-0.38 ± 0.41	-0.19 ± 0.30	$\bar{b} \to \bar{s}s\bar{s}$	*BABAR* [5], Belle [22]
$\eta' K_S^0$	$+0.33 \pm 0.25$	-0.08 ± 0.16		*BABAR* [17], Belle [22]
$D^{*-}D^{*+}$	-0.32 ± 0.45	$+0.02 \pm 0.27$	$\bar{b} \to \bar{c}c\bar{d}$	*BABAR* [19], Belle
$D^{*-}D^{+}$	$+0.24 \pm 0.70$	-0.22 ± 0.38		*BABAR* [20]
$D^{*+}D^{-}$	$+0.82 \pm 0.76$	-0.47 ± 0.42		
$J/\psi\pi^0$	$+0.47 \pm 0.41$	$+0.26 \pm 0.29$	$\bar{b} \to \bar{c}c\bar{d}$	*BABAR* [21], Belle [23]

Provided that the tree contribution is small, $S_{\eta' K_S^0}$ is equal to $\sin 2\beta$.

The $B \to D^{(*)-}D^{(*)+}$ modes receive contribution from Cabibbo-suppressed $\bar{b} \to \bar{c}c\bar{d}$ tree and $\bar{b} \to \bar{d}$ penguin amplitudes. The latter is believed to be much smaller than the former. At present only the $B^0 \to D^{*-}D^{*+}$ and the $B^0 \to D^{*\mp}D^{\pm}$ have been observed. Using a sample of 126 ± 13 events selected in the pseudoscalar to vector-vector $B^0 \to D^{*+}D^{*-}$ mode, we performed a transversity analysis to disentangle the $CP = +1$ and $CP = -1$ components of this decay. As anticipated [18] we find that the decay proceeds mostly through the CP-even component: $R_\perp = 0.07 \pm 0.06 \pm 0.03$. If the penguin contribution can be neglected, the imaginary part of the CP parameter $(\lambda_{D^*D^*})_{CP=+1}$ is equal to $-\sin 2\beta$. We obtain [19]:

$$|(\lambda_{D^*D^*})_{CP=+1}| = 0.98 \pm 0.25 \pm 0.13 \quad \text{and} \quad \mathrm{Im}\,(\lambda_{D^*D^*})_{CP=+1} = 0.31 \pm 0.43 \pm 0.13 \; . \tag{12}$$

From a sample of 113 ± 13 events reconstructed in the modes $D^{*-}D^{+}$ and $D^{*+}D^{-}$, we measure [20]:

$$\mathcal{B}(B^0 \to D^{*\pm}D^{\mp}) = (\,8.8\, \pm 1.0, \pm 1.3\,) \times 10^{-4} \text{ and } \mathcal{A}_{D^*D} = (\,-3\, \pm 11\, \pm 5\,)\% \; , \tag{13}$$

where $\mathcal{A}_{D^*D} \equiv (\mathcal{N}_{D^{*+}D^-} - \mathcal{N}_{D^{*-}D^+})/(\mathcal{N}_{D^{*+}D^-} + \mathcal{N}_{D^{*-}D^+})$ is the time-integrated charge asymmetry. Our preliminary time-dependent results in these modes are:

$$\begin{aligned} S_{D^{*-}D^+} &= -0.24 \pm 0.69 \pm 0.12 \; , \quad C_{D^{*-}D^+} = -0.22 \pm 0.37 \pm 0.10 \; , \\ S_{D^{*+}D^-} &= -0.82 \pm 0.75 \pm 0.14 \; , \quad C_{D^{*+}D^-} = -0.47 \pm 0.40 \pm 0.12 \; , \end{aligned} \tag{14}$$

where $S_{D^{*-}D^+}$ and $S_{D^{*+}D^-}$ are equal to $-\sin 2\beta$ if penguin contributions are negligible.

The $B^0 \to J/\psi\pi^0$ decay is a $\bar{b} \to \bar{c}c\bar{d}$ transition. The dominant color-suppressed tree amplitude is also Cabibbo-suppressed. The sub-dominant penguin amplitude is CKM-suppressed but has a different weak phase, which might spoil the relation $S_{J/\psi\pi^0} = -\sin 2\beta$. With a sample of 40 ± 7 signal events, we obtain [21]:

$$S_{J/\psi\pi^0} = +0.05 \pm 0.49 \pm 0.16 \; , \quad C_{J/\psi\pi^0} = +0.38 \pm 0.41 \pm 0.09 \; . \tag{15}$$

The time-dependent results presented here are combined in Table 1 with corresponding results from Belle when available. More statistics is needed to draw conclusions on the slight discrepancy between the values of $\sin 2\beta$ measured in $(\bar{c}c)K$ and $(\bar{s}s)K$ modes.

6 Time-dependent analyses in charmless modes

The $B \to \pi^+\pi^-$ decay receives contributions from CKM-suppressed $\bar{b} \to \bar{u}$ tree and $\bar{b} \to \bar{d}$ penguin amplitudes. In the absence of penguin contribution the phase of $\lambda_{\pi\pi}$ is $-2(\beta+\gamma)$, which is equivalent to 2α using the triangle relation $\alpha + \beta + \gamma = \pi$ (here, γ is the phase of $V_{ub}{}^*$). In presence of penguin contribution the modulus and phase of $\lambda_{\pi\pi}$ are modified: $\lambda_{\pi\pi} \equiv |\lambda_{\pi\pi}|\, e^{2i\alpha_{\rm eff}}$. The observables are $C_{\pi\pi} = (1-|\lambda_{\pi\pi}|^2)/(1+|\lambda_{\pi\pi}|^2)$ and $S_{\pi\pi} = \sqrt{1 - C^2_{\pi\pi}}\, \sin 2\alpha_{\rm eff}$. One condition for direct *CP* violation ($C_{\pi\pi} \neq 0$) is that the relative strong phase $\delta_{\pi\pi}$ between the tree and penguin amplitudes be non-zero, while $\alpha - \alpha_{\rm eff}$ depends on the absolute ratio $|P/T|$ of the penguin to tree amplitude.

We perform a simultaneous $\pi^+\pi^-/K^+\pi^-$ analysis. The Cherenkov angles as measured in the DIRC enter directly the likelihood function as discriminating variables to distinguish between the $\pi^+\pi^-$ and $K^+\pi^-$ modes. The separation that results from this discrimination is excellent. The maximum likelihood fit identifies $\mathcal{N}_{K\pi} = 589 \pm 30$ and $\mathcal{N}_{\pi\pi} = 157 \pm 7$ signal candidates out of a large continuum-dominated sample of events. From the self-tagged $K\pi$ sample we measure Δm as a cross-check and find a value in full agreement with the actual value. From the $\pi\pi$ sample we measure [24]:

$$S_{\pi\pi} = +0.02 \pm 0.34 \pm 0.05\ , \quad C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.04\ . \tag{16}$$

The statistical errors are quoted from the likelihood fit and are in good agreement with expectation from Monte-Carlo studies. Our result is well into the physical region ($C^2_{\pi\pi} + S^2_{\pi\pi} \leq 1$) and does not bring evidence for either direct or mixing-induced *CP* violation in the $B \to \pi^+\pi^-$ mode: *BABAR* does not confirm the observation by Belle of large *CP* violation effects in this mode [25].

The time-dependent study of the $B \to \pi^+\pi^-\pi^0$ decay is in principle a promising way for a model-independent determination of angle α [26]. In practice the description of the interfering resonant structure in the 3π Dalitz plot will introduce some level of model dependence in the extraction of α, which has to be evaluated. With the present statistics we perform a quasi two-body analysis where we select bands around the ρ^+ and ρ^- in the $\pi^+\pi^-\pi^0$ Dalitz plot, excluding the interfering region at the intersection between the two bands, where the charge assignment ($\rho^+\pi^-$ or $\rho^-\pi^+$) is ambiguous. The analysis is similar to that in the $\pi^+\pi^-$ mode, with the additional complications of a π^0 in the final state and of a larger background from poorly-known rare B decays. We perform a simultaneous $\rho\pi/\rho K$ analysis that yields $\mathcal{N}_{\rho\pi} = 428 \pm 42$ and $\mathcal{N}_{\rho K} = 120 \pm 28$ signal events. The small ratio $\rho K/\rho\pi$ is an indication that the penguin contribution is smaller in the $\rho\pi$ mode than it is in the $\pi\pi$ mode, as anticipated. We obtain the preliminary branching fractions and charge asymmetry:

$$\begin{aligned} \mathcal{B}(B^0 \to \rho^\pm\pi^\mp) &= (\,22.6\ \pm 1.8\ \pm 2.2\,) \times 10^{-6} \\ \mathcal{B}(B^0 \to \rho^\pm K^\mp) &= (\ 7.3\,^{+1.3}_{-1.2}\ \pm 1.3\,) \times 10^{-6} \\ \mathcal{A}_{\rho K} &= (\,+28\ \pm 17\ \pm 8\,)\%\ . \end{aligned} \tag{17}$$

From the $\rho\pi$ sample we update our time-dependent *CP* measurements [27] in this mode. In addition to a global charge asymmetry $\mathcal{A}_{\rho\pi} = (\,+18\ \pm 8\ \pm 3\,)\%$, we obtain:

$$\begin{gathered} S_{\rho\pi} = +0.19 \pm 0.24 \pm 0.03\,,\ C_{\rho\pi} = +0.36 \pm 0.18 \pm 0.04\,, \\ \Delta S_{\rho\pi} = +0.15 \pm 0.25 \pm 0.03\,,\ \Delta C_{\rho\pi} = +0.28 \pm 0.19 \pm 0.04\,. \end{gathered} \tag{18}$$

$S_{\rho\pi}$ and $C_{\rho\pi}$ are parameters that measure mixing-induced and direct *CP* violation, respectively. $\Delta C_{\rho\pi}$ and $\Delta S_{\rho\pi}$ are dilution parameters: $\Delta C_{\rho\pi}$ is linked to the ratio of $B^0 \to \rho^-\pi^+$ and $B^0 \to \rho^+\pi^-$ amplitudes, and its value is consistent with predictions; $\Delta S_{\rho\pi}$ is a non-trivial combination of strong and weak phase differences. The values of $\mathcal{A}_{\rho\pi}$ and $C_{\rho\pi}$ can be interpreted as a $\sim 2.5\sigma$ deviation from the hypothesis of no-direct *CP* violation in this mode, from which no claim can be made.

7 Conclusions

A broad experimental program of time-dependent measurements in a variety of modes related to angles β and α of the Unitarity Triangle is underway at *BABAR*. With the exception of the main $\sin 2\beta$ measurement in golden channels, these measurements have poor statistical significance, but promise exciting results with an order-of-magnitude larger statistics at B factories. Eventually this array of measurements will put strong constraints on the fundamental parameters of the CKM model in the Standard Model and, perhaps, reveal the presence of New Physics in processes involving B meson mixing and decay.

8 Acknowledgements

I am grateful to my *BABAR* colleagues for their help and support in preparing this talk. I would like to congratulate the organizers for the outstanding scientific quality of the conference.

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